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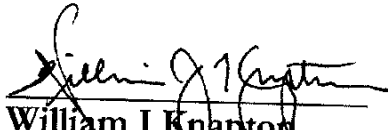
October 9, 2008

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**William J Knapton**  
**Professional Translator**

## Specification

RESONATOR OPERATING WITH BULK ACOUSTIC WAVES AND CIRCUIT  
WITH THE RESONATOR

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[0001]

The invention relates to a resonator operating with bulk acoustic waves (or FBAR, Thin Film Bulk Acoustic Wave Resonator), also known as BAW resonator (Bulk Acoustic Wave Resonator), as well as a circuit constructed of such resonators.

10

## State of the art

[0002]

BAW resonators are suitable, in particular, for band-pass, high-frequency filters in modern filter technology, and can be used, for example, in mobile communication

15 devices.

[0003]

A resonator operating with bulk acoustic waves has a piezoelectric layer that is disposed between two metal layers (electrodes). It is known that a sequence of layers can also be used instead of only one piezoelectric layer. The layers are deposited consecutively on a substrate and structured into resonators that are electrically connected to one another and together can constitute, for example, a filter circuit, especially a band-

20

pass filter. Such a band-pass filter can also be used together with another filter in a duplexer.

[0004]

- 5           Figure 1 shows the equivalent circuit diagram of a BAW resonator. Outside a frequency range surrounding the resonant frequency, the resonator is characterized by a static capacitor  $C_0$  and, in proximity to the resonant frequency, by the series connection of a resistor  $R_m$ , a capacitor  $C_m$  and an inductive resistor  $L_m$ . The static capacitor is essentially defined by the resonator surface area and the thickness of the piezoelectric
- 10   layer. The resistor  $R_m$  describes losses in the resonator, while the capacitor  $C_m$  and the inductive resistor  $L_m$  determine the resonant frequency

$$f_r = \frac{1}{2\pi\sqrt{L_m C_m}} .$$

The ratio  $C_m/C_0$  determines the coupling of the resonator. The coupling coefficient  $k$  of the resonator is linked to the resonant frequency  $f_r$  and the antiresonant frequency  $f_a$ :

$$k^2 = \frac{f_a^2 - f_r^2}{f_a^2} ,$$

15

wherein

$$f_a = f_r \sqrt{1 + C_m/C_0} .$$

[0005]

A band-pass filter is characterized by a transfer function that has, in particular, a passband and several stopbands. The passband is, in turn, characterized by its bandwidth, the insertion attenuation in the passband and the edge steepness at the edge of the

5 passband.

[0006]

It is known that two BAW resonators SR1 and SR2 (as depicted schematically in Figure 2) can be acoustically coupled with one another if, for example, they are arranged

10 in a stack one on top of the other. In this connection, said resonators form a series connection between a port P1 and a port P2, e.g., in a stacked-crystal arrangement, in which two resonators share a common electrode that is connected to ground (see Figure 3), or are arranged in a coupled-resonator arrangement, in which a coupling layer KS is arranged between the upper electrode E2 of the lower resonator and the lower

15 electrode E3 of the upper resonator, and said electrodes are connected to ground (see Figure 4). A first resonator in Figure 3 comprises a piezoelectric layer PS1 arranged between two electrodes E1 and E2, and an acoustic mirror AS arranged below the electrode E1, said acoustic mirror resting on a carrier substrate TS. Above the first resonator, a second resonator is arranged that comprises a piezoelectric layer PS2, which

20 is arranged between the electrode E2 and an electrode E3. Electrode E1 is connected to port P1, electrode E3 to port P2 and electrode E2 to ground.

[0007]

The layer system shown in Figure 4 consists of a first resonator arranged on a carrier substrate TS, a coupling layer KS disposed above it and a second resonator  
5 arranged above the coupling layer KS. The first resonator is arranged as described in Figure 3 and is connected between port P1 and ground. The second resonator contains (from bottom to top) two electrodes E3 and E4 and a piezoelectric layer PS2 arranged between said electrodes, the second resonator being connected between port P2 and ground. The coupling layer KS arranged between said resonators provides for acoustic  
10 coupling between these resonators.

[0008]

Filters constructed of acoustically coupled resonators are characterized by a high stopband suppression. However, the edge steepness and, with it, the adjacent channel  
15 selectivity are comparatively low, due to the absence of defined pole positions in proximity to the passband.

[0009]

It is known that BAW resonators can be connected in a ladder-type or a lattice-  
20 type construction. The advantage of the lattice-type arrangement of the resonators in a band-pass filter is that the selection of such a filter in stopband areas well outside the

passband is very good, ranging, for example, between -40 and -60 dB. The disadvantage of said filter arrangement consists in a low edge steepness of the passband. For this reason, it is difficult, in this type of filter arrangement, to achieve sufficient attenuation of the signal in the stopbands in proximity to the passband.

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[0010]

Considerable edge steepness is required in some applications. In the case of duplexers that are suitable for the PCS telecommunications standard, for example, a decline in the transmission function from ca. -3 dB to significantly below -40 dB within a frequency range of only 20 MHz must be guaranteed. Previously known band-pass filters that are constructed of BAW resonators do not satisfy such requirements, due to additional frequency shifts in the edges in response to temperature change or as a result of existing production tolerances (which, in the case of a filter operating at ca. 2 GHz and having BAW resonators that contain a piezoelectric layer of ALN, can amount to several MHz).

10  
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[0011]

It is known, from the reference EP 0949756 A2, that a series connection of stacked resonators acoustically coupled with one another, as well as additional resonators instead of only one resonator in a filter circuit, improves edge steepness in the passband of the filter. The disadvantage of this solution, however, is that it requires a great deal of space.

20

[0012]

The problem of the present invention is to specify a BAW resonator that guarantees a large edge steepness of a band-pass filter constructed of such resonators.

5 [0013]

The underlying problem of the invention is solved, in accordance with the invention, by a resonator according to claim 1. Advantageous embodiments may be derived from further claims.

10 [0014]

The invention specifies a resonator operating with bulk acoustic waves (also known as BAW resonator - Bulk Acoustic Wave Resonator - or FBAR - Thin Film Bulk Acoustic Wave Resonator), which is constructed of a sequence of layers containing the following layers: a lower layer region that comprises a first electrode, an upper layer region that comprises a second electrode and, between the two, a piezoelectric layer. A  
15 capacitor is connected in parallel or in series to said resonator.

[0015]

The parallel connection of a BAW resonator and a capacitor  $C_a$  instead  
20 of a non-connected resonator reduces the effective coupling of the BAW resonator (that is, the distance between the resonant and antiresonant frequency of the resonator), in that the

effective static capacitance  $C'_0$  is increased,  $C'_0 = C_0 + C_a$ . In this connection, the resonant frequency  $f_r$  of the new circuit (series resonance, or the resonant frequency of the series resonant circuit formed by  $C_m$ ,  $L_m$  and  $R_m$ ) remains unchanged relative to the resonant frequency  $f_r$  of the (non-connected) resonator,  $f_r = f_r$ . In contrast, the antiresonant

- 5 frequency,  $f_s = f_r \sqrt{1 + C_m/C'_0}$  (parallel resonance, or the resonant frequency of the parallel resonant circuit formed by  $C'_0$ ,  $C_m$ ,  $L_m$  and  $R_m$ ) is lower than the antiresonant frequency  $f_a = f_r \sqrt{1 + C_m/C_0}$  (parallel resonance, or the resonant frequency of the parallel resonant circuit formed by  $C_0$ ,  $C_m$ ,  $L_m$  and  $R_m$ ) of the (non-connected) resonator. As a result, the edge steepness of a band-pass filter comprising such BAW resonators is increased.

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[0016]

The series connection of a BAW resonator and a capacitor  $C_a$  instead of a non-connected resonator reduces the effective coupling of a BAW resonator (that is, the distance between the resonant and the antiresonant frequency of the resonator). In the

- 15 connection, the antiresonant frequency  $f_a$  of the circuit (parallel resonance, or the resonant frequency of the parallel resonant circuit formed by  $C_0$ ,  $C_m$ ,  $L_m$  and  $R_m$ ) remains unchanged relative to the antiresonant frequency  $f_a$  of the resonator,  $f_a = f_a$ . In contrast, the resonant frequency  $f_r = f_r \sqrt{1 + C_m/(C_a + C_0)}$  (series resonance, or the resonant frequency of the series resonant circuit formed by  $C_a$ ,  $C_m$ ,  $L_m$  and  $R_m$ ) of said circuit is higher than
- 20 the resonant frequency  $f_r$  (series resonance, or the resonant frequency of the series



resonant circuit formed by  $C_m$ ,  $L_m$  and  $R_m$ ) of the resonator. As a result, the edge steepness of a band-pass filter comprising such BAW resonators is increased.

[0017]

5           In an advantageous embodiment of the invention, the resonator of the invention is arranged on a carrier substrate. It is also possible to arrange the resonator of the invention over an air gap provided in the carrier substrate.

[0018]

10           The first and the second electrode consist of an electrically conductive material, such as a metal or a metal alloy.

[0019]

15           The piezoelectric layer preferably consists of AlN, but can also consist of another material with piezoelectric properties (such as ZnO). It is also possible that the piezoelectric layer comprises a plurality of adjacent or separated, identical or different layers with piezoelectric properties.

[0020]

20           It is possible that the first and/or the second electrode has a multilayer structure consisting of two or more adjacent layers of different materials. It is also possible that the

piezoelectric layer in the resonator of the invention comprises two or more adjacent or separated layers of different materials.

[0021]

5           It is possible that, additionally, a layer resistant to dielectric discharge is arranged between the first and the second electrode, said layer protecting the resonator against electric arcing between the electrodes.

[0022]

10           The connection, according to the invention, of a capacitor in parallel to a BAW resonator can be accomplished in a filter constructed, for example, in a ladder-type construction, in a lattice-type construction or as an SCF (Stacked Crystal Filter), as well as of any combination of said BAW resonators according to the invention.

15           [0023]

          It is possible to provide for the connection of a capacitor in parallel to a BAW resonator in only one series branch or in a plurality of series branches of a filter. It is also possible to provide for the connection of a capacitor in parallel to a BAW resonator in only one parallel branch or a plurality of parallel branches of a filter. In a further  
20   embodiment, it is possible that the connection of a capacitor in parallel to a BAW

resonator be provided in at least one series branch and in at least one parallel branch of the filter.

[0024]

5           In said embodiments, the value of the capacitor connected, according to the invention, in parallel to a BAW resonator preferably ranges between 0.1 and 10 pF.

[0025]

          It is advantageous if the coupling of the resonator is reduced only in the series  
10   branches or only in the parallel branches of a filter or a duplexer by the parallel connection of the corresponding capacitors.

[0026]

          It is possible to implement the capacitor connected in parallel to a BAW resonator  
15   by connecting a discrete capacitor in parallel to the BAW resonator. Another possibility is to realize such a capacitor in the carrier substrate by means of structured metal layers. It is also possible to arrange an additional dielectric layer between the electrodes of the BAW resonator to increase the capacitance of the BAW resonator. This dielectric layer can be arranged between the piezoelectric layer and one of the electrodes or between two  
20   piezoelectric layers.

[0027]

The parasitic capacitance of the respective resonator can also be deliberately selected to be as large as possible, for example by enlarging the electrode surface to improve the edge steepness of the filter constructed of such resonators. Other realizations  
5 of the invention not cited here are also possible.

[0028]

It is possible that the lower and/or upper layer region of the resonator according to the invention consists of one or more layers. It is also possible that an acoustic mirror is  
10 realized in the lower and/or in the upper layer region, said mirror comprising at least two alternating layers having different acoustic impedance.

[0029]

The acoustic mirror consists of alternating layers, each having a high and a low  
15 acoustic impedance, each of their layer thicknesses comprising approximately a quarter wavelength of the acoustic principal mode (relative to the velocity of propagation of the acoustic wave in the respective material). The acoustic mirror thus provides one or a plurality of boundary surfaces that, at the resonant frequency, reflect the acoustic wave  
back into the resonator and prevent the wave from escaping in the direction of the carrier  
20 substrate.

[0030]

In a further advantageous embodiment of the invention, one of the layers of the acoustic mirror can simultaneously constitute one of said electrodes.

5 [0031]

The use, according to the invention, of a BAW resonator with a capacitor connected in parallel in the circuit of a band-pass filter increases the edge steepness of the passband of the band-pass filter. As a result, the attenuation of the signal is increased in the stopbands in proximity to the passband. This is especially advantageous in the case of  
10 realization of a duplexer circuit having such a band-pass filter.

[0032]

The underlying goal of the invention is, furthermore, achieved by the embodiment variant of the invention described below.

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[0033]

This embodiment according to the invention specifies an electric circuit containing a resonator stack that comprises at least two resonators arranged one on top of the other and operating with bulk acoustic waves and at least one additional resonator or resonator  
20 stack having BAW resonators. Each of said resonators operating with bulk acoustic waves comprises a lower electrode, an upper electrode and a piezoelectric layer arranged

between the two. In this connection, the resonators arranged one on top of the other in the resonator stack form a series circuit, e.g., in a stacked crystal arrangement (when both resonators have a shared electrode) or a coupled resonator arrangement (when a coupling layer is provided between the upper electrode of the lower resonator and the lower  
5 electrode of the upper resonator).

[0034]

The upper electrode of the lower resonator operating with bulk acoustic waves and the lower electrode of the upper resonator operating with bulk acoustic waves, said  
10 electrodes being arranged in the resonator stack, is electrically connected here to one of the electrodes of at least one additional resonator or resonator stack.

[0035]

The connection according to the invention can be viewed as a basic element of a  
15 ladder-type arrangement or (in the case of a suitable connection) of a lattice-type arrangement of individual resonators, at least two of said resonators being acoustically coupled with one another and arranged one on top of the other. It is possible that two BAW resonators arranged one on top of the other in a stack here realize two series resonators or parallel resonators of the ladder-type arrangement or of the lattice-type  
20 arrangement. It is also possible that two BAW resonators arranged one on top of the other

in a stack realize one series resonator and one parallel resonator of the ladder-type arrangement or the lattice-type arrangement.

[0036]

5           A coupling layer is preferably provided between the upper electrode of the lower resonator operating with bulk acoustic waves and the lower electrode of the upper resonator operating with bulk acoustic waves, said electrodes being arranged in the resonator stack.

10   [0037]

The at least one additional resonator can, for example, be a resonator operating with bulk acoustic waves, a resonator operating with surface acoustic waves, an LC resonator or a resonator stack as specified above.

15   [0038]

The second electrode of the at least one additional resonator, said electrode not being connected to the resonators arranged one on top of the other in the resonator stack, can be connected to ground or to a subsequent resonator or to a resonator stack not yet specified.

20

[0039]

The circuit according to the invention represents an advantageous combination of different filter arrangements known in the art, such as the arrangement of the resonators stacked one on top of the other and acoustically coupled with one another, as well as a ladder-type arrangement or a lattice-type arrangement. The transfer function of a filter whose basic elements realize the circuit according to the invention, as compared with the transfer function of a filter constructed of resonator stacks known in the art, exhibits significantly steeper edges in the passband of the filter. This results in exceptionally good adjacent channel selectivity of the filter.

10

[0040]

The circuit according to the invention, which, for example, consists of a resonator stack and a resonator electrically connected to it as specified above, preferably constitutes a basic element of a filter.

15

[0041]

It is possible that a plurality of parallel resonators, each of which is arranged in a parallel branch of different basic elements electrically connected to one another, are acoustically connected to one another and/or arranged one on top of the other. It is also possible that, instead of only one resonator being realized in the parallel branch (parallel resonator) of a basic element of the circuit according to the invention, two (preferably

20



coupled with one another) parallel resonators connected in series or in parallel are realized.

[0042]

5           It is also possible that more than only two series resonators are arranged one on top of the other and/or acoustically coupled with one another.

[0043]

          The basic elements of the circuit according to the invention described above can be  
10   combined with one another in any manner.

[0044]

          In the following, the invention is explained in greater detail on the basis of figures that are schematic and, therefore, not true to scale.

15

[0045]

          Figure 1 shows an equivalent circuit diagram of a BAW resonator

[0046]

20           Figure 2 shows the circuit diagram of a resonator stack

[0047]

Figure 3 shows a resonator stack with acoustically coupled BAW resonators in schematic cross section (state of the art)

5 [0048]

Figure 4 shows another example of a resonator stack with acoustically coupled BAW resonators and a coupling layer in schematic cross section (state of the art)

[0049]

10 Figure 5a shows an equivalent circuit diagram of a BAW resonator with a capacitor connected in parallel to it, according to the invention

[0050]

15 Figure 5b shows an equivalent circuit diagram of a BAW resonator with a capacitor connected in series to it, according to the invention

[0051]

Figure 6a shows a basic element of a filter realized in ladder-type construction with a capacitor connected in parallel to a BAW resonator in the series branch

20

[0052]

Figure 6b shows the transfer function of a filter realized in ladder-type construction without and with a capacitor connected in parallel to a BAW resonator in the series branch

5

[0053]

Figure 7 shows a basic element of a filter realized in ladder-type construction with a capacitor connected in parallel to a BAW resonator in the parallel branch

10 [0054]

Figure 8a shows an embodiment of a filter realized in ladder-type construction with capacitors connected in parallel to BAW resonators in the series branches

[0055]

15 Figure 8b shows the transfer function of a filter realized in lattice-type construction without and with a capacitor connected in parallel to a BAW resonator in the series branch

[0056]

20 Figure 9 shows an embodiment of a filter realized in lattice-type construction with capacitors connected in parallel to BAW resonators in the parallel branches

[0057]

Figure 10 shows a connection, according to the invention, of a resonator stack in the series branch and of an additional BAW resonator in the parallel branch, in circuit  
5 diagram (a) and in schematic cross section (b), respectively

[0058]

Figure 11 shows an advantageous embodiment of a connection, according to the invention, of a resonator stack and of an additional BAW resonator in schematic cross  
10 section

[0059]

Figure 12 shows a connection, according to the invention, of a resonator stack in the series branch and of an additional resonator stack in the parallel branch, in circuit  
15 diagram (a) and in schematic cross section (b), respectively

Figures 1-4 have already been discussed earlier.

[0060]

Figure 5a shows an equivalent circuit diagram of a BAW resonator with a  
20 capacitor  $C_a$  connected in parallel to it. Outside the resonant frequency range, the resonator is characterized by a static capacitor  $C_0$  and, in proximity to the resonant

frequency, by a resistor  $R_m$ , a capacitor  $C_m$  and an inductive resistor  $L_m$ . The resistor  $R_m$  describes losses in the resonator, while the capacitor  $C_m$  and the inductive resistor  $L_m$  determine the resonant frequency. The ratio  $C_m/C_0$  determines the coupling of the resonator. The addition of a capacitor  $C_a$  connected in parallel to the resonator results in  
5 reduction of the effective coupling of the resonator now determined by  $C_m/(C_0 + C_a)$  instead of  $C_m/C_0$ .

[0061]

Figure 5b shows an equivalent circuit diagram of a BAW resonator with a  
10 capacitor  $C_a$  connected in series to it.

[0062]

An example of a connection of two BAW resonators RA and RB in ladder-type construction and a capacitor  $C_a$  connected in parallel to one of said resonators is shown in  
15 Figure 6a. Resonator RA is arranged in a series branch and resonator RB in a parallel branch of the circuit. Two resonators connected in this manner represent, for example, a basic element of a ladder-type filter known in the art.

[0063]

20 In Figure 6a, the capacitor  $C_a$  is integrated in the series branch of the circuit. In this connection, it is connected in parallel to the series resonator RA, as a result of which the

steepness of the right edge of the transfer function in the passband can be controlled or increased. Such a basic element can be used, for example, in the transmission filter (Tx filter) of a duplexer, especially a PCS duplexer.

5 [0064]

Figure 6b shows the transfer function  $S_{21}$  of a filter realized in ladder-type construction without and with a capacitor connected in parallel to a BAW resonator in the series branch. The transfer function of the filter constructed of BAW resonators in the ladder-type construction known in the art is indicated by a dashed line 11. The transfer  
10 function of the filter according to the invention in ladder-type construction with a capacitor connected in parallel to a BAW resonator in the series branch is indicated by a continuous line 12, wherein the transfer function, in this case, has a steeper right edge of the passband.

15 [0065]

In Figure 7, the capacitor  $C_a$  is integrated in the parallel branch of the circuit. It is also connected in parallel to the parallel resonator RB, as a result of which the steepness of the left edge of the transfer function in the passband can be controlled and/or increased. Such a basic element can be used, for example, in the reception filter (Rx filter) of a  
20 duplexer, especially a PCS duplexer.

[0066]

The capacitor  $C_a$  can be arranged on a carrier substrate, together with the BAW resonator. The capacitor  $C_a$  can also constitute a discrete component with external electrodes, said component being electrically connected to the BAW resonator as

5 described above.

[0067]

It is also possible that the capacitor  $C_a$  is realized in the metallized layers of the (multilayer) carrier substrate and, as described above, is electrically connected to the

10 BAW resonator by means of, for example, feedthroughs, bump connectors or bond wires.

[0068]

An example of a connection of two BAW resonators RA and RB in lattice-type construction and a capacitor  $C_a$  connected in parallel to one of said resonators is shown in

15 Figure 8a. A resonator RA is arranged in a series branch, and a resonator RB in a parallel branch of the circuit. Figure 8a shows two pairs of resonators that are connected in this manner and that constitute, for example, a basic element of a filter realized in lattice-type construction known in the art.

[0069]

In Figure 8a, two capacitors  $C_a$  are each integrated in a series branch of the circuit. They are each connected in parallel to the corresponding series resonator RA, as a result of which the steepness of the right edge of the transfer function in the passband can be controlled or increased. Such a basic element can be used, for example, in the transmission filter (Tx filter) of a duplexer, especially a PCS duplexer.

[0070]

Figure 8b shows the transfer function S21 of a filter realized in lattice-type construction without and with a capacitor connected in parallel to a BAW resonator in the series branch. The transfer function of the filter constructed of BAW resonators in the lattice-type construction known in the art is indicated by a dashed line 11. The transfer function of the filter according to the invention in lattice-type construction with a capacitor connected in parallel to a BAW resonator in the series branch is indicated by a continuous line 12, wherein the transfer function, in this case, has a steeper right edge of the passband.

[0071]

In Figure 9, two capacitors  $C_a$  are each integrated in a parallel branch of the circuit. They are each connected in parallel to the parallel resonator RB, as a result of which the steepness of the left edge of the transfer function in the passband can be



controlled or increased. Such a basic element can be used, for example, in the reception filter (Rx filter) of a duplexer, especially a PCS duplexer.

[0072]

5           Figure 10a shows the circuit diagram of a connection, according to the invention, of a resonator stack that comprises the BAW resonators SR1 and SR2, in the series branch, and of an additional BAW resonator PR in the parallel branch. The resonator stack is connected between ports P1 and P2. An example of a realization of such a circuit is shown in schematic cross section in Figure 10b. The resonator stack comprises the

10   piezoelectric layer PS1 that is arranged between two electrodes E1 and E2 (center electrode). The piezoelectric layer PS2 is arranged above them. An electrode E4 connected to the port 2 lies on the piezoelectric layer PS2. The port P1 is electrically connected to the electrode E1. The layer sequence E1, PS1 and E2 realizes, for example, the resonator SR1 in accordance with Figure 10a. The layer sequence E2, PS2 and E4

15   realizes, for example, the resonator SR2 in accordance with Figure 10a. Here, the resonator PR in the parallel branch of the circuit according to Figure 10a is realized by the layer sequence E6 (electrode), PS3 (piezoelectric layer) and E5 (electrode), the electrode E5 being electrically connected to the center electrode E2. In this embodiment, the electrode E6 is connected to ground. It is also possible that it is connected to another

20   circuit not shown here.

[0073]

Figure 11 shows, in schematic cross section, an advantageous embodiment of the connection, according to the invention, of a resonator stack and an additional BAW resonator. The resonator stack consists, from bottom to top, of a first electrode E1, a first piezoelectric layer PS1, a second electrode E2, a coupling layer KS1, a third electrode E3, a second piezoelectric layer PS2 and a fourth electrode E4. The resonator stack forms two resonators arranged one on top of the other and coupled with one another by means of the coupling layer (corresponding to SR1 and SR2 in Figure 10a), and is connected between ports P1 and P2. The parallel branch of the circuit is formed by an additional resonator that consists of a third piezoelectric layer PS3 and electrodes E5 and E6 surrounding it. Electrodes E2 and E3 are connected to electrode E5. Here, electrode E6 is connected to ground. It is also possible that it is connected to another circuit not shown here.

[0074]

Figure 12a shows the circuit diagram of a connection, according to the invention, of a resonator stack in the series branch and another resonator stack in the parallel branch between ports P1 and P2. The first resonator stack consists of two resonators SR1 and SR2 connected in series. The second resonator stack consists of two resonators PR1 and PR2 connected in series. An example of a realization of this circuit is shown in schematic cross section in Figure 12b. The first resonator stack is constructed as shown in Figure 10b. The second resonator stack consists, from bottom to top, of an electrode E6

(connected to ground, for example), a piezoelectric layer PS3, a center electrode E5 that is electrically connected to electrode E2 of the first resonator stack, a piezoelectric layer PS4 and an electrode E7 (connected to ground, for example).

5 [0075]

Though not specifically shown in the figure, the (lower) resonators are, in this case, also arranged on a carrier substrate, wherein an air gap or an acoustic mirror is provided, in each case, between the carrier substrate and resonator.

10 [0076]

In the interest of clarity, the invention was only described on the basis of a few embodiments, but is not limited to these. Other variations are possible, especially in light of the possible combinations of the basic elements and arrangements presented above, as well as the number of layers in said layer regions of the resonator according to the invention. The invention is not limited to a specific frequency range or a specific scope of application. Each of the layers of the resonator according to the invention (e.g., the piezoelectric layer or the electrode) can have a multilayer structure. The resonator according to the invention can also contain a plurality of (possibly non-adjacent) piezoelectric layers, or more than only 2 electrodes.

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## TRANSLATION

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[0077]

The electrical connections (including the connections to ground) in the embodiments described can contain discrete elements, such as inductive resistors, capacitors, delay lines or matching networks.

Claims

1. Resonator operating with bulk acoustic waves having a layer sequence  
containing:

- 5           - a lower layer region that comprises a first electrode,  
          - an upper layer region that comprises a second electrode,  
          - a piezoelectric layer that is arranged between the first and second electrode,  
          - wherein a capacitor is connected in parallel or in series with said resonator.

10           2. Resonator according to claim 1 that is arranged on a carrier substrate.

          3. Resonator according to claim 1 or 2 in which the upper and lower layer region  
each consists of one layer or a plurality of layers.

15           4. Resonator according to at least one of claims 1-3 in which the first and/or the  
second electrode consists of a plurality of layers that are made of at least two different  
materials.

          5. Resonator according to at least one of claims 1-4 in which an acoustic mirror is  
20 realized in the upper and/or in the lower layer region, said mirror comprising at least two  
alternating layers having different acoustic impedance.

6. Resonator according to claim 5 in which one of the layers of the acoustic mirror is one of said electrodes.

5           7. Resonator according to at least one of claims 1-6 that is arranged over an air gap provided in the carrier substrate.

8. Filter having a ladder-type arrangement, a lattice-type arrangement or a stacked crystal filter arrangement, wherein this filter contains at least one resonator according to at  
10   least one of claims 1-7 in a series branch and/or a parallel branch.

9. Filter according to claim 8 in which a capacitor that reduces the coupling of the corresponding resonators is connected in parallel or in series only to the resonators in the series branches or only to the resonators in the parallel branches, respectively.

15

10. Duplexer containing at least one filter according to claim 8 or 9.

11. Electrical circuit containing:

          a resonator stack that comprises at least two resonators arranged one on top of the  
20   other and operating with bulk acoustic waves, and  
          at least one additional resonator or resonator stack,

wherein said resonators operating with bulk acoustic waves each contain a lower electrode, an upper electrode and a piezoelectric layer arranged between the two,

wherein the upper electrode of the lower resonator operating with bulk acoustic waves and the lower electrode of the upper resonator operating with bulk acoustic waves,  
5 said electrodes being arranged one on top of the other in the resonator stack, is electrically connected to one of the electrodes of the at least one additional resonator or resonator stack.

12. Circuit according to claim 11 in which the second electrode of the at least one  
10 additional resonator is connected to ground.

13. Circuit according to claim 11 or 12 in which a coupling layer is provided between the upper electrode of the lower resonator operating with bulk acoustic waves and the lower electrode of the upper resonator operating with bulk acoustic waves, said  
15 electrodes being arranged in the resonator stack.

14. Circuit according to one of claims 11-13 in which the at least one additional resonator is a resonator operating with bulk acoustic waves, a resonator operating with surface acoustic waves, an LC resonator or a resonator stack that comprises at least two  
20 resonators arranged one on top of the other and operating with bulk acoustic waves.

## Summary

Resonator operating with bulk acoustic waves and circuit with the resonator

5           The invention relates to a resonator operating with bulk acoustic waves (BAW resonator, BAW = Bulk Acoustic Wave) and band-pass filters constructed of such resonators. To increase the edge steepness of the passband of a BAW band-pass filter, the invention proposes reducing the effective coupling of a BAW resonator by using the parallel connection of a BAW resonator and a capacitor instead of only one resonator. In  
10 addition, to increase the edge steepness of the passband, the use of a connection of coupled BAW resonators in the series branch of a filter circuit with another resonator or resonator stack in the parallel branch of the filter circuit is proposed, the additional resonator or resonator stack being connected to the center electrode of the resonator stack specified initially.

15

Figure 5



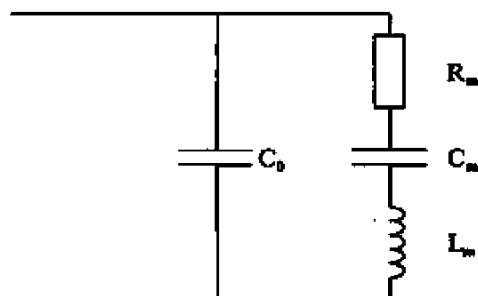


Fig. 1

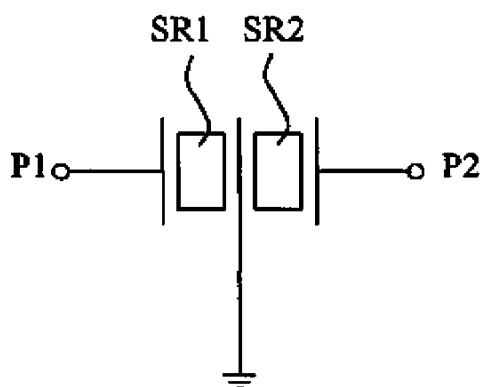


Fig. 2 (State of the Art)

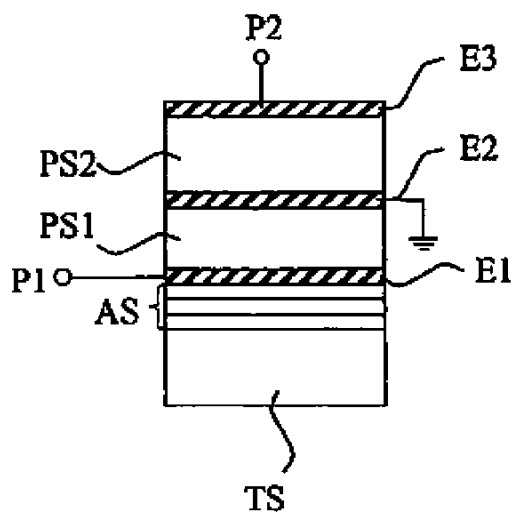


Fig. 3 (State of the art)

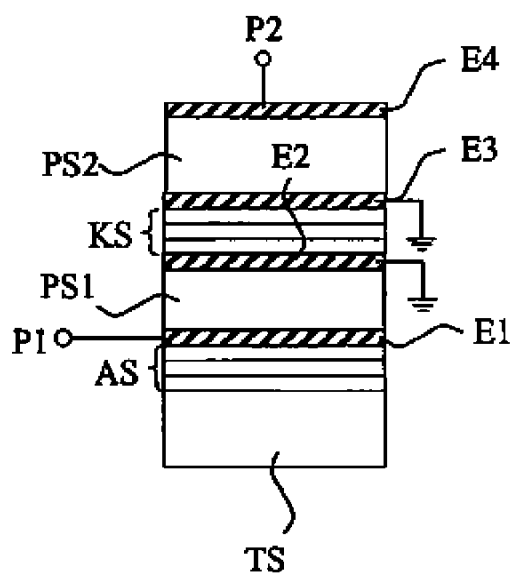
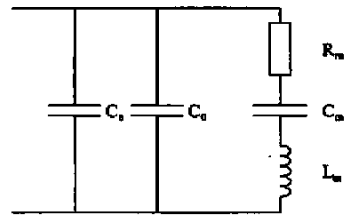


Fig. 4 (State of the art)



\* Fig. 5a

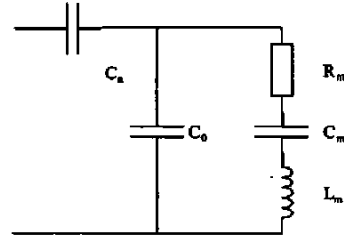


Fig. 5b

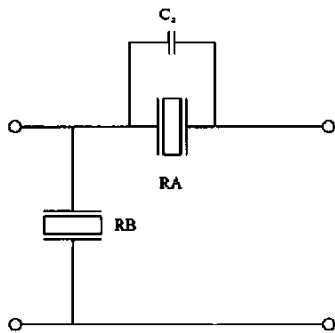


Fig. 6a

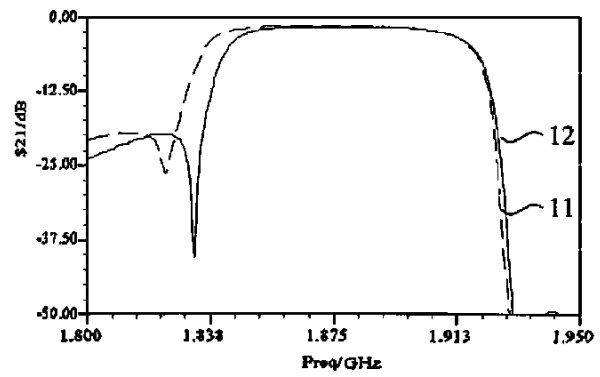


Fig. 6b

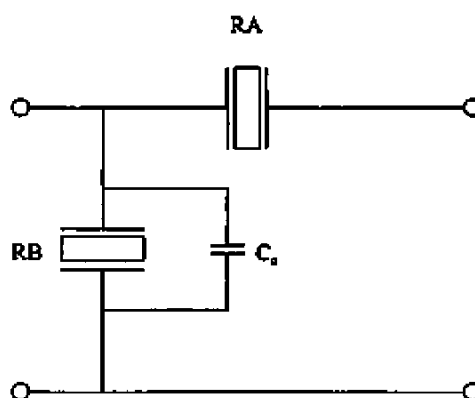


Fig. 7

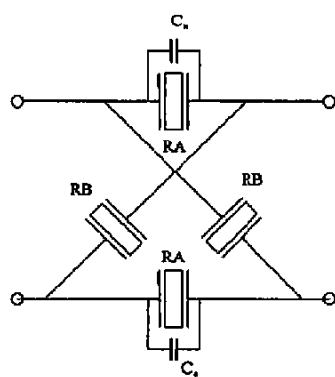


Fig. 8a

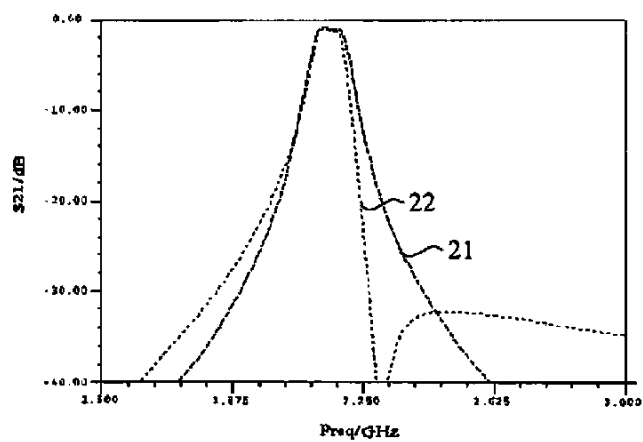


Fig. 8b

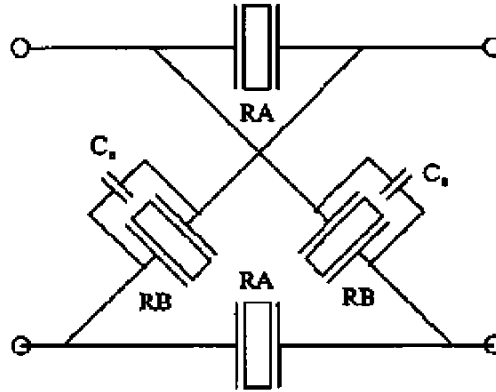


Fig. 9

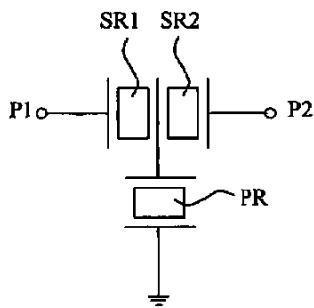


Fig. 10a

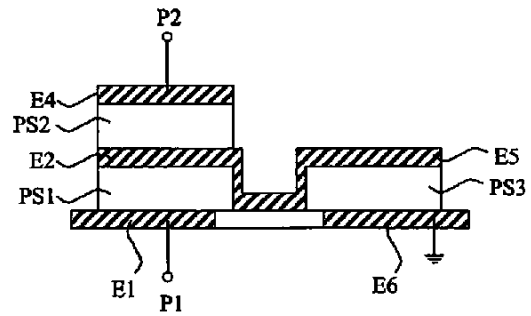
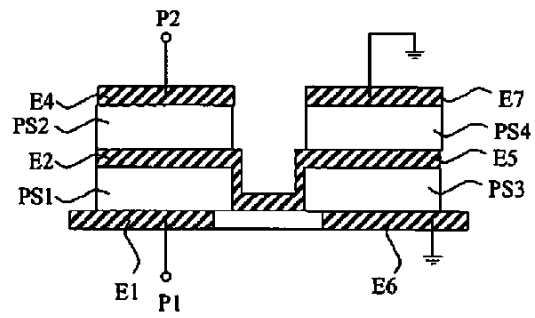
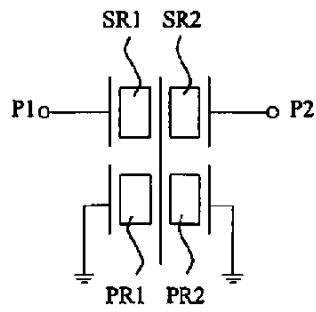
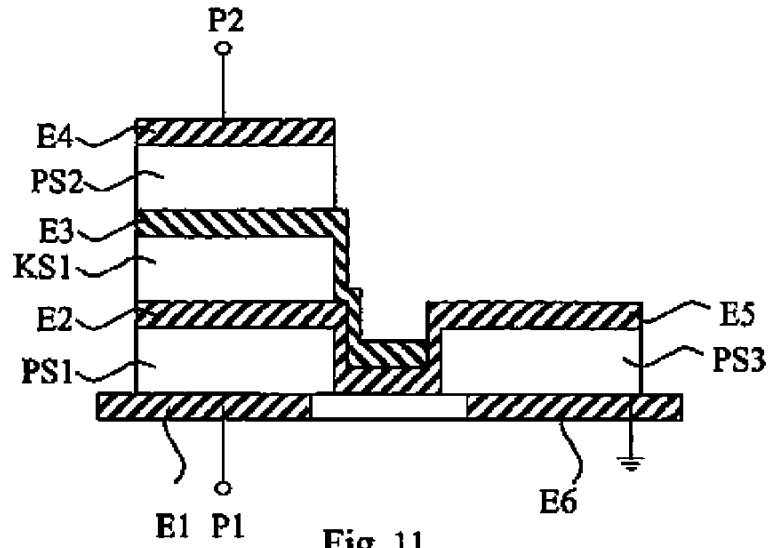


Fig. 10b



## TRANSLATION

14219-080US1 / P2002,0843 US N  
DE 10246791

## ERRATA

1. On page 13, first full paragraph, line three, "is" should read "are."
- 5    2. On page 24, first full paragraph, line ten, "S52" should read "PS2."
3. On page 30, second paragraph, line two, "is" should read "are."